The Utilization of Direct Electron Pairs for the Energy Measurement of Ultrarelativistic Cosmic Rays

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A great deal of progress has been made in our fundamental understanding of the production of direct electron pairs by relativistic heavy ions in matter. The past discrepancies between theory and measurement have been resolved due, in part, to the collaborative work conducted at MSFC, the University of Alabama in Huntsville (UAH), and the University of Tennessee (UT). The accelerator measurements performed by the MSFC/UAH/UT group at the European Center for Nuclear Research (CERN) using relativistic oxygen and sulfur ion beams are summarized in figure 166 along with previous accelerator measurements. Included in this presentation of the direct pair yield is the only other relativistic heavy ion pair measurement at CERN conducted by an Oakridge National Laboratory (ORNL) collaboration using a magnetic field to identify the positron member of the pair and determine its momentum spectrum. The measured direct pair yield from the heavy ion exposures have been corrected for background, pair energy cut-off and bandwidth differences, and normalized as indicated in figure 166 to facilitate comparison with the theory. These recent direct pair yield results based on the heavy ion exposures compare well with a modern calculation performed at MSFC (solid curve).

This gives us confidence in both the measurements and the theory so that it is now possible to consider the application of the direct electron pair process to the measurement of the primary energy of the heavy cosmic rays above 10^{12} electron volts. Unlike other methods dependent on the electromagnetic interaction (e.g., Cerenkov and transition radiation), this energy measurement technique has the advantage of not saturating at ultrarelativistic energies. Through the MSFC/UAH/UT effort, the physical characteristics of the direct electron pairs have been determined. The direct pair energy varies from a few million electron volts (MeV) to several hundred MeV and the emission angle distribution peaks close to the forward direction. This basic information on direct electron pairs will be used in a Monte Carlo simulation of a generic direct electron pair detector to aid in the development of several promising detector designs. If the design effort is successful, a measurement of the ultrarelativistic cosmic ray energy spectra using the direct pair method will provide important clues concerning possible multiple sources of cosmic rays and potential evidence of several acceleration mechanisms.

Derrickson, J.H., et al.: Physical Review A. 51:1253, 1995.

Derrickson, J.H., et al.: 24th International Cosmic Ray Conference, Rome, Italy. Vol. 3, pp. 641, 1995.

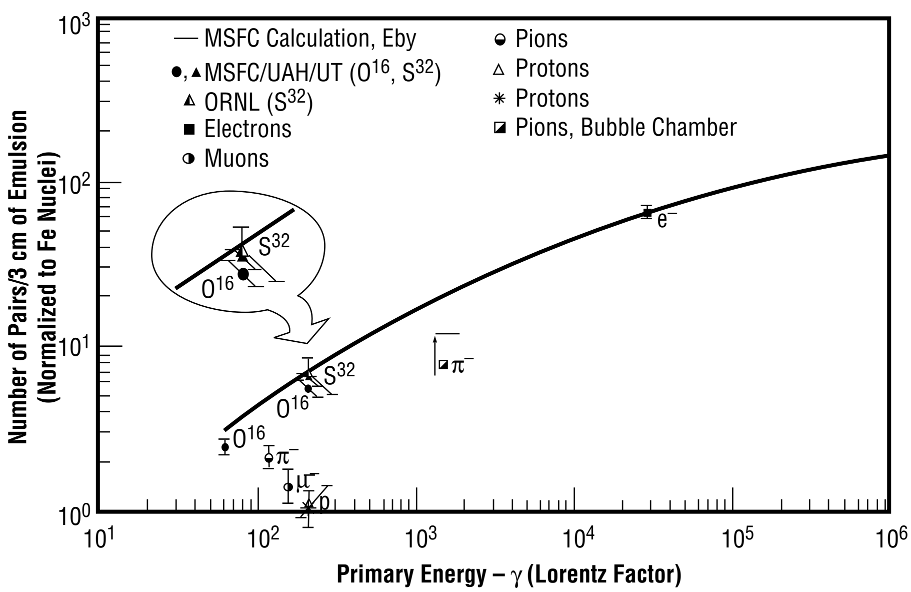

FIGURE 166.—The direct pair production arbitrarily normalized to the equivalent yield of an Fe nucleus in 3 cm of emulsion as a function of the primary energy of the projectile expressed in terms of the Lorentz factor, (γ). This unusual normalization can be tied to the interest the cosmic ray community has in applying the direct pair method to measuring the heavy energetic cosmic rays. The recent MSFC/UAH/UT results (●, ▲) are compared to the measurements from Kinzer et al. (1968, ◒), Cary et al. (1971, ■), Butt et al. (1973, ∗), Jain et al. (1974, △, ◑), Forney et al. (1975, ◪), Vane et al. (1994, ▲). The arrow and bar indicate a correction to the bubble chamber yield to compensate for the high momentum cutoff (10 MeV/c). The solid curve is the calculated total direct pair yield including atomic screening due to Eby (1991). The heavy ion data has been corrected for background and pair momentum detection limits.

Eby, P.B.: Nuclear Instruments and Methods in Physics Research A. 336:189, 1993.

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Biographical Sketch: Dr. James Derrickson is a space scientist at the Space Sciences Laboratory located at MSFC. He has experience in the study of the space radiation environment focusing on the field of high energy cosmic ray research. He received his Ph.D. in 1983 from the University of Alabama in Huntsville.